How to Evaluate Climate Model Simulations Using both Surface and Satellite Observations

Xiquan Dong, Baike Xi, and Aaron Kennedy, Uni. of North Dakota

Pat Minnis and Mandy Khaiyer, NASA LaRC

Tony DelGenio and Audrey Wolf, NASA GISS

Shaocheng Xie and Steve Klein, DOE LLNL

Objectives

1) To use both ARM radar-lidar observed and GOES/CERES satellite-derived cloud fraction (CF) to evaluate model simulated CF over the ARM SGP site during the January-December of 2000.

2) To use both ARM observed surface fluxes and GOES/CERES satellite observed/derived TOA fluxes as constraints to evaluate model simulations.

3) To compare the vertical distributions of cloud fraction observed by ARM radar-lidar and simulated by GFDL AM2, NCAR CAM3, and NASA GISS SCM.

Data: ARM Surface Observations

ARM radar-lidar data have been averaged into the same temporal and vertical resolutions as three models:

- **Averaged 5-min data into one-hour temporal resolution**
- **Averaged 90-m into ~25 mb vertical distribution for each layer**
- **35 levels from surface to 16 km**

Cloud Fraction (CF)=Hours of detected clouds by radar-lidar
Total hours when both radar-lidar worked

SW fluxes: Measured by up/down looking PSPs.
LW fluxes: Measured by up/down looking PIRs.
Surface Air temperature: Measured by in situ sensors mounted on a 10-m tower at the ARM SGP site

DATA: GOES/CERES Satellite Observations

- CF and cloud optical depth were derived from the multispectral GOES imager data using CERES cloud algorithms
- TOA fluxes using NB (GOES) to BB (CERES) conversion
- 30-min temporal resolution → 1-hr
- 0.5° spatial resolution (derived from pixel data) → 2x2.5°

Data: NASA GISS SCM

- - 2x2.5° centered on ARM SGP CF
  - 35 levels (25-mb vertical resolution)
  - hourly output
- Driven by ARM hourly continuous forcing

- This SCM uses an RH based parameterization for stratiform clouds (Sundqvist et al. 1989, Del Genio et al. 1996) with recent modifications to the scheme outlined in Schmidt et al. (2006)

- Clouds can form in any layer and are overlapped in time rather than instantaneously in space with assumptions equivalent to mixed maximum-random overlapping

Data: GFDL AM2 and NCAR CAM3

- 1-hour temporal resolution
- 35 levels from surface to ~100 mb, ~25 mb resolution
- Spatial domain: AM2: 2^{o}X2.5^{o}
  CAM3: 2.875^{o}x2.875^{o}
- Both models are initialized at 00Z with ECMWF reanalysis data (ERA-40) and outputted from 12-36 hours of forecasts for the year 2000 at the SGP site. (run climate models as forecast models, no forcing was used)

All surface, satellite and model results have been averaged into the same temporal, vertical, and/or spatial resolutions. If we have enough samples (≥ 3 years), we should have a statistical comparison.

Convergent of temporal (ARM) and spatial (GOES/Model) averages

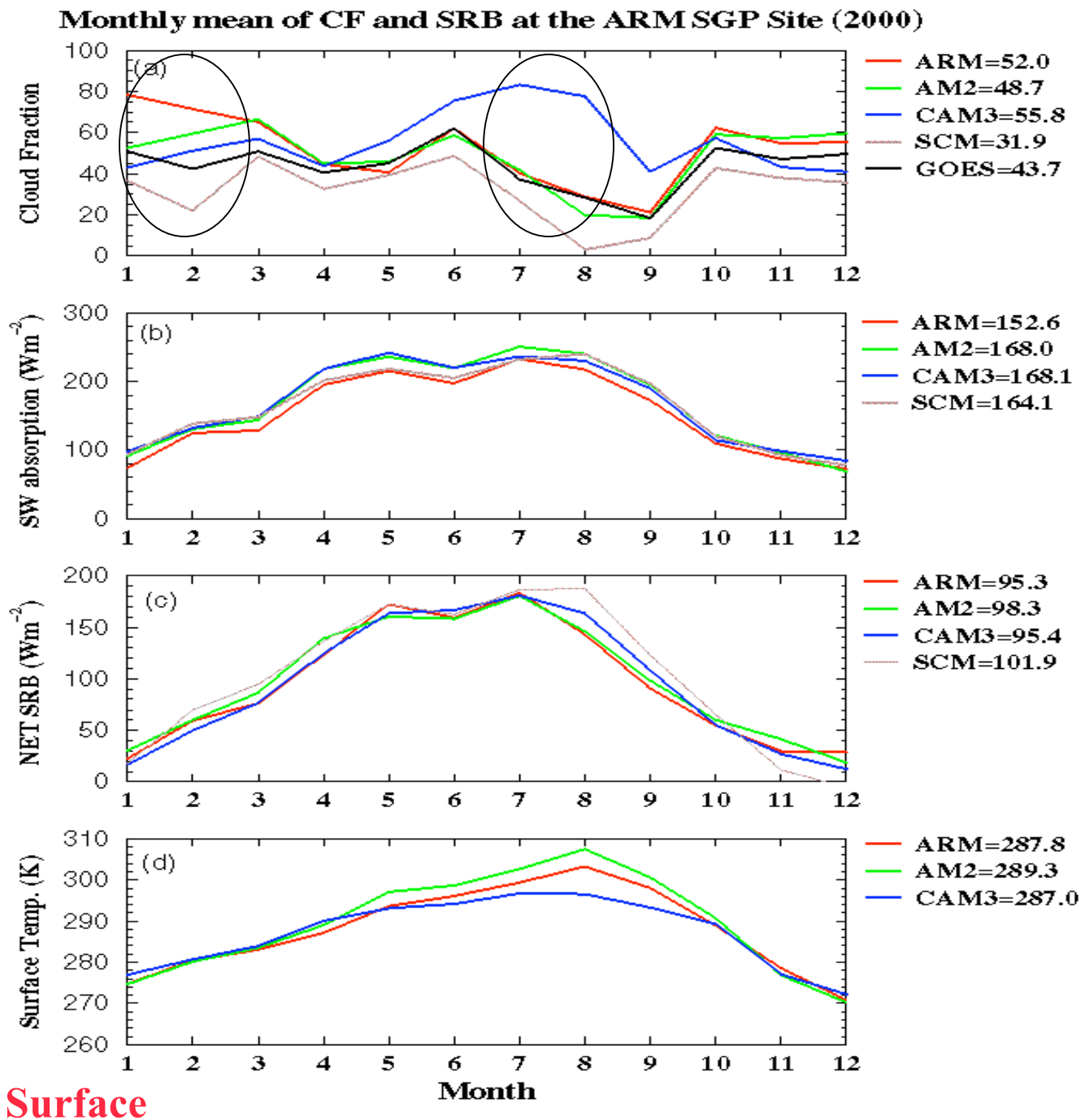
Area (GOES) vs. Area (Model) (Apples to Apples)	Point (ARM) vs. Area (GOES/Model) (Apples to Oranges)
Cld. Amount = Cld Amount Cld. Frequency = Cld. Frequency Cld. Fraction = Cld. Fraction	Cld. Amount ≠Cld. Amount Cld. Frequency ≠ Cld. Frequency Cld. Fraction = Cld. Fraction

However:

$$\lim_{a \to 0} f_{area}(a) = f_{point} \qquad \lim_{t \to x} f_{point}(t) = f_{area}$$

Variables will become identical!

Section 1:
Monthly means of CF, SRB, and TOA radiation budget
(From January to Dec. 2000)



Surface

Using ARM derived CF as baseline:

GOES: Excellent except for Jan-March

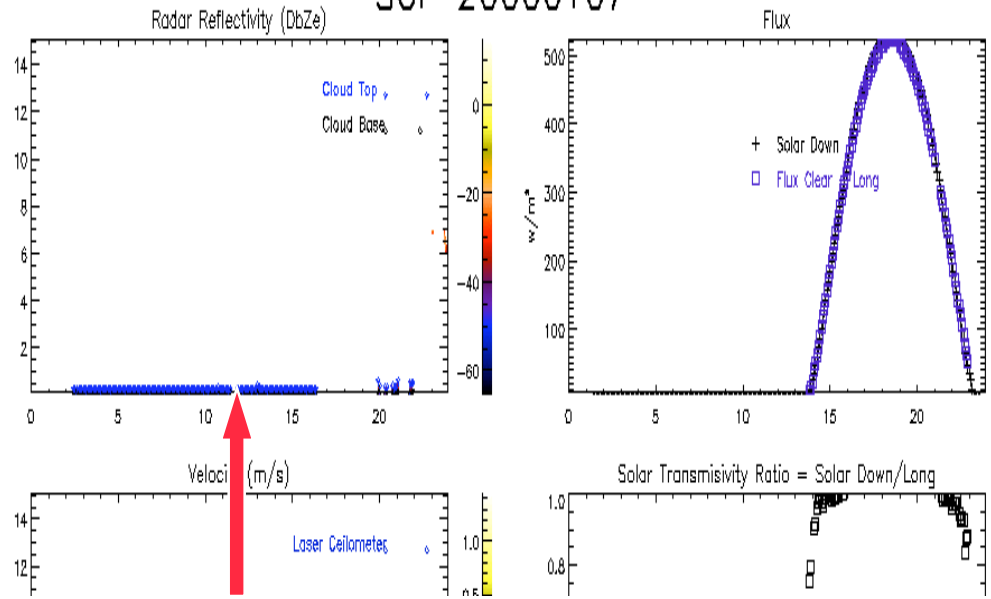
AM2: Agree well

CAM3: Overestimate

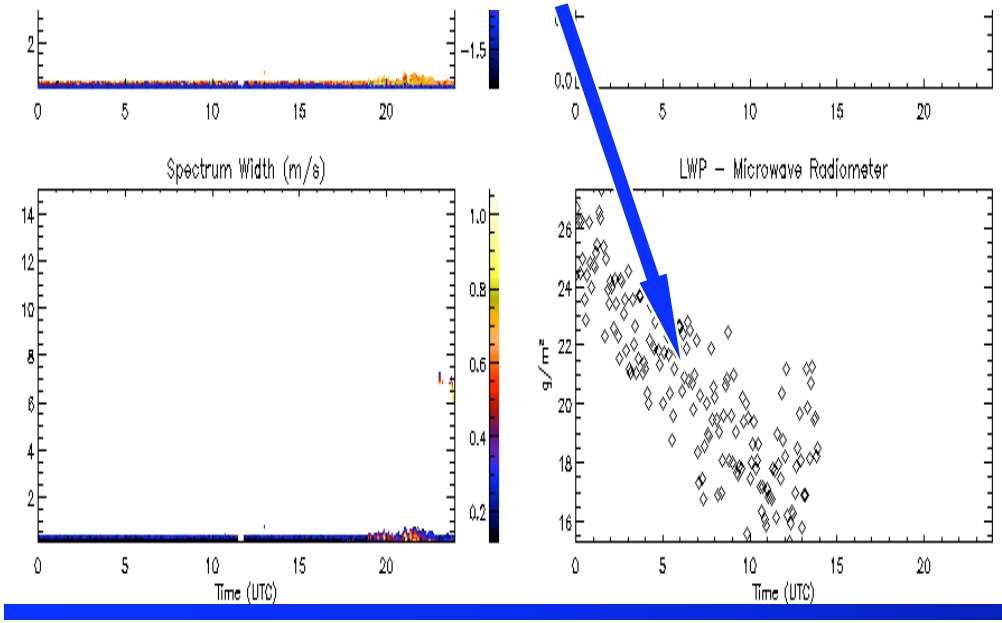
SCM: Underestimate

The nearly same SW absorption at surface indicates that CAM3 simulated clouds are optically thin, while SCM are optically thick

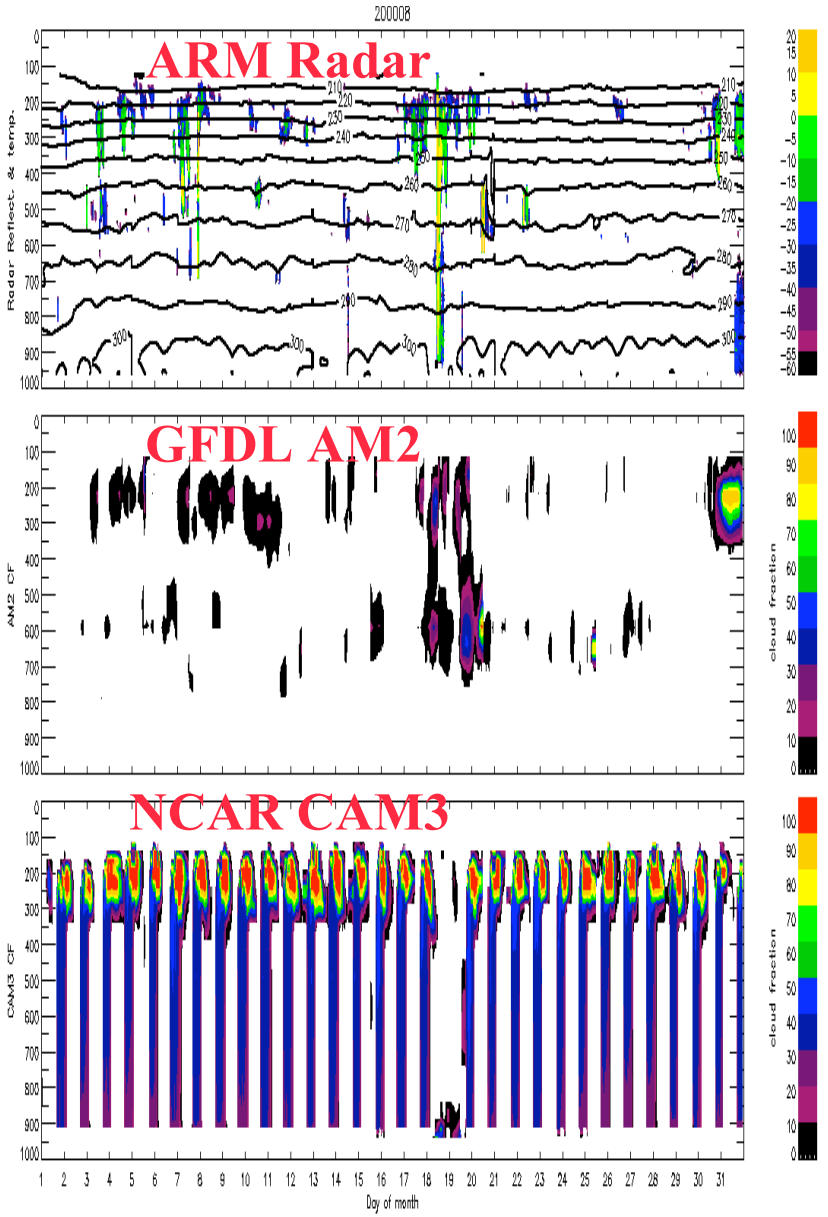
The AM2 NET SRB is 3 Wm^{-2} more than ARM, which leads to 1.5 degree higher in surface temp. Overall, AM2 simulated clouds and radiation agree better with ARM observations



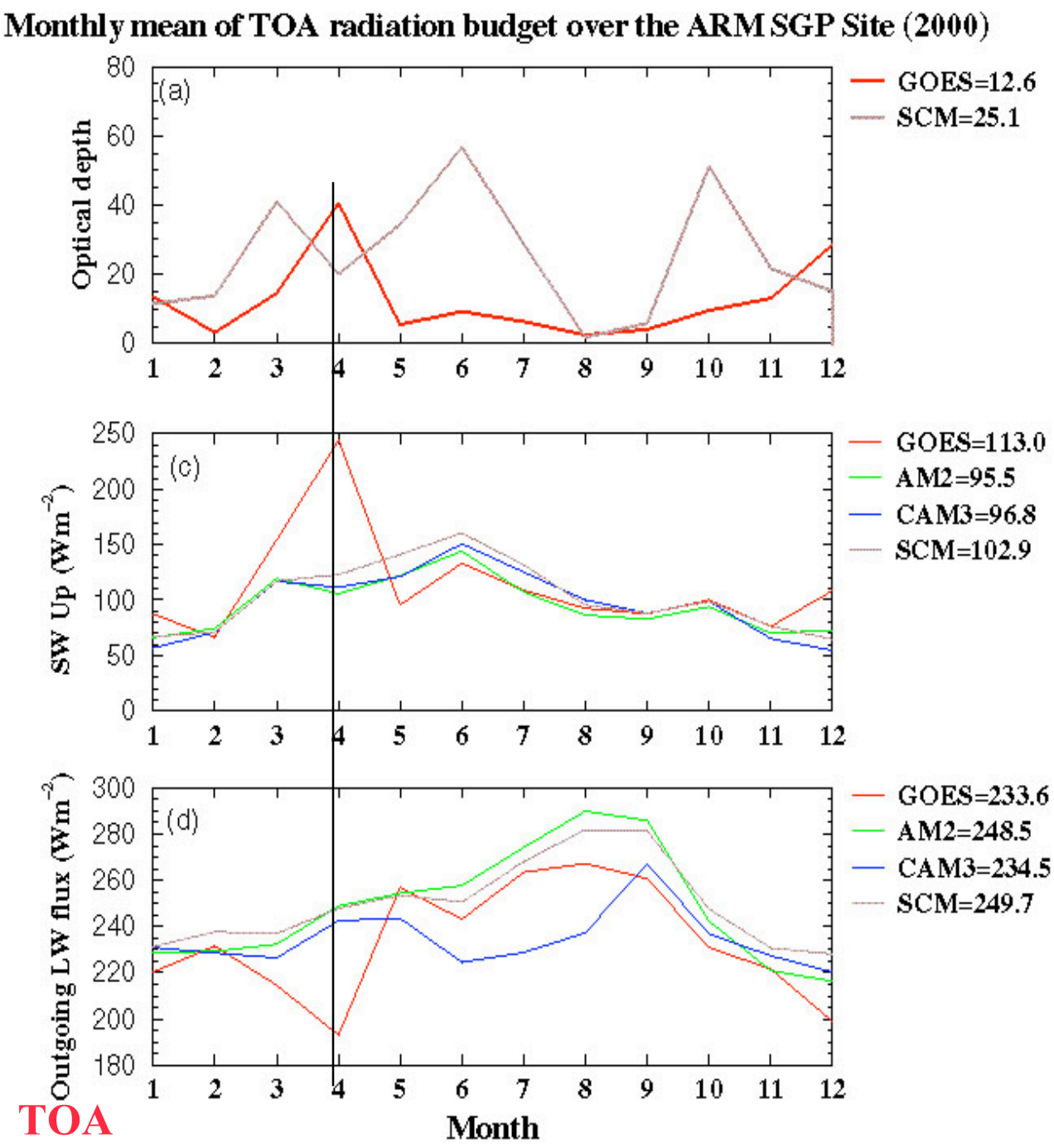
During Jan-Feb., more low-level clouds/fogs detected by ARM radar-lidar and microwave radiometer, but not observed by GOES and simulated by models



August 2000



CAM3 simulated more optically thin cirrus clouds during summer



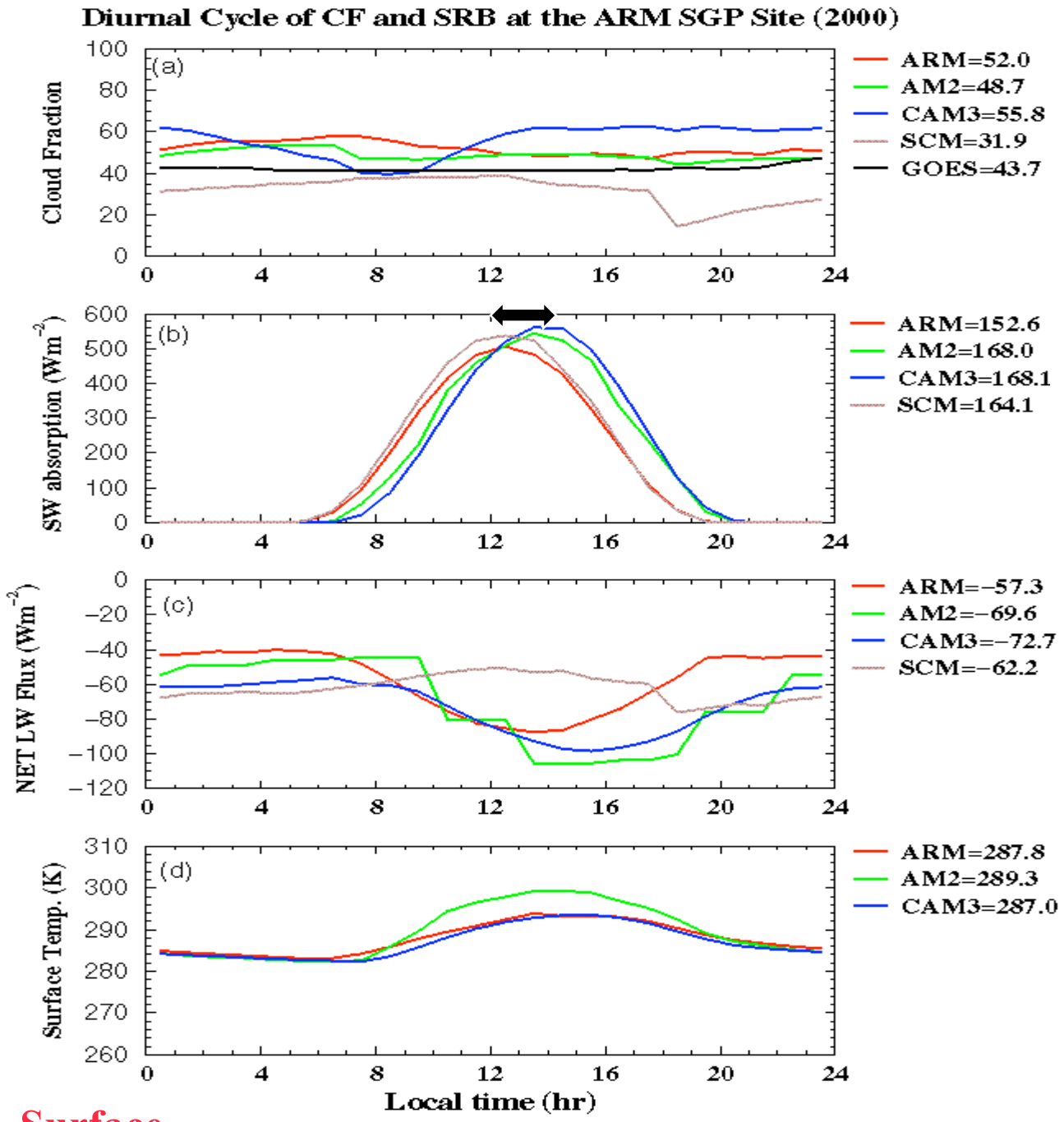
TOA

Compared to GOES derived optical depth, SCM are optically thick.

On annual average, the difference in SW up and OLR are 16 Wm^{-2}

Higher optical depth leads to more reflected SW and less OLR, but inconsistent with ARM

Section 2: Diurnal Cycle (Same data sets as Monthly mean)



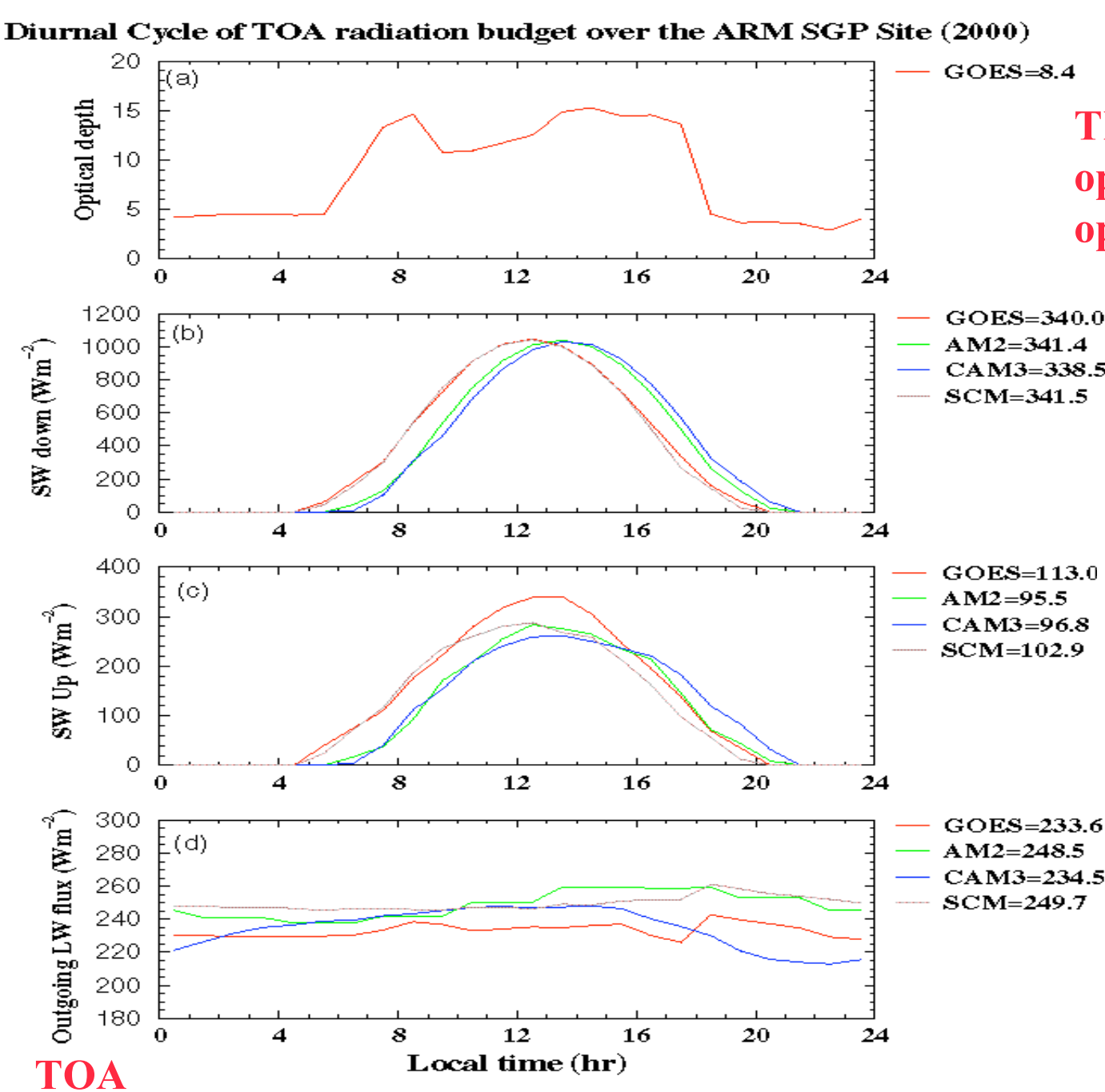
Surface

No strong diurnal variation in CF

Both AM2 and CAM3 have 2 hours delay compared to ARM/SCM

During daytime, the more negative NET LW flux correlates with more LW emission from surface (higher Tsfc).

Higher NET LW in SCM is due to more simulated low-level clouds



TOA

The nighttime GOES optical depth are optically thin only

The SW down and up in both AM2 and CAM3 are the same as their surface counterparts, 2-hr delay

NO strong diurnal variation in OLR

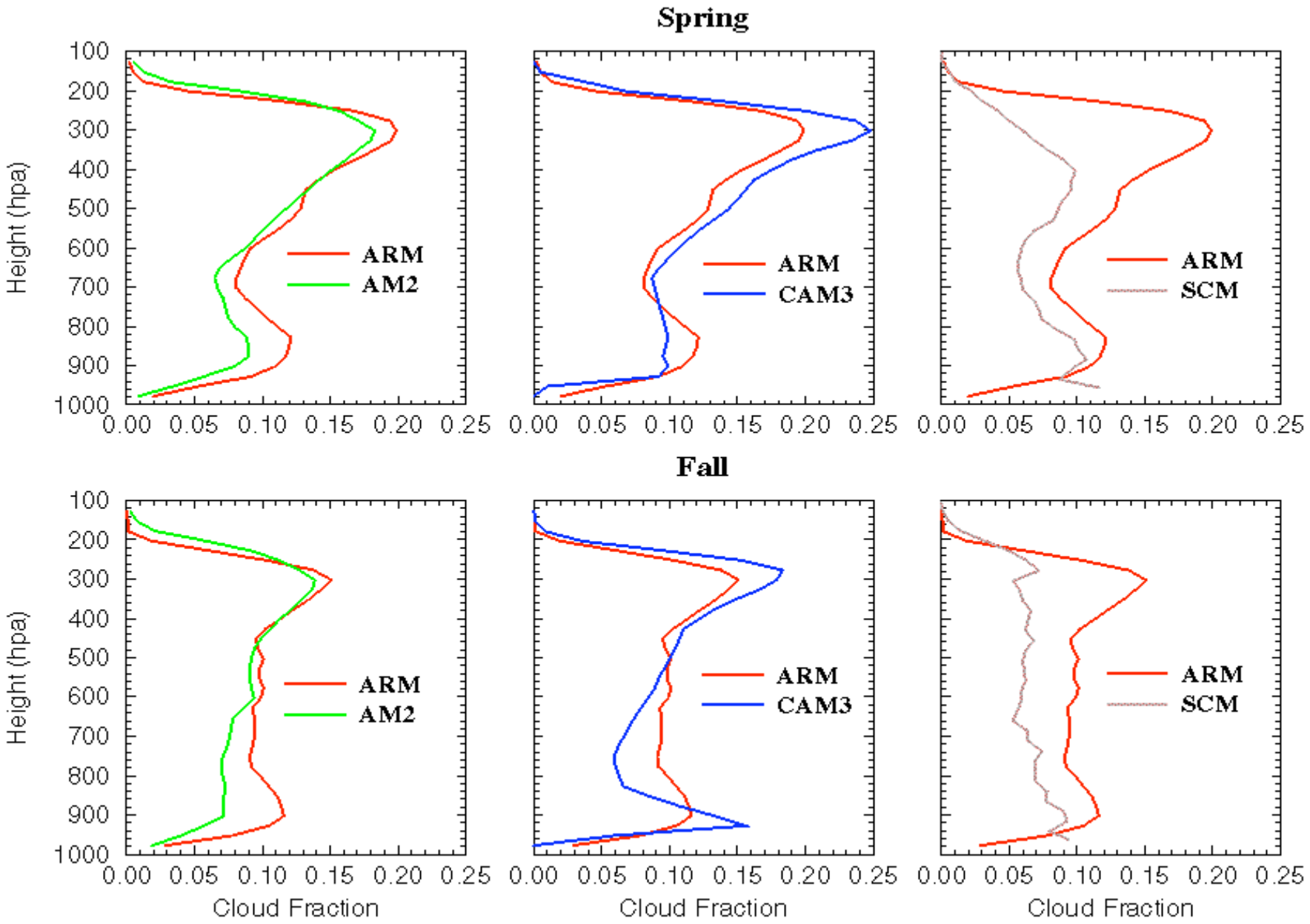
Section 3: Vertical Distributions of Cloud Fraction

ARM radar-lidar data have been averaged into the same temporal and vertical resolutions as three models:

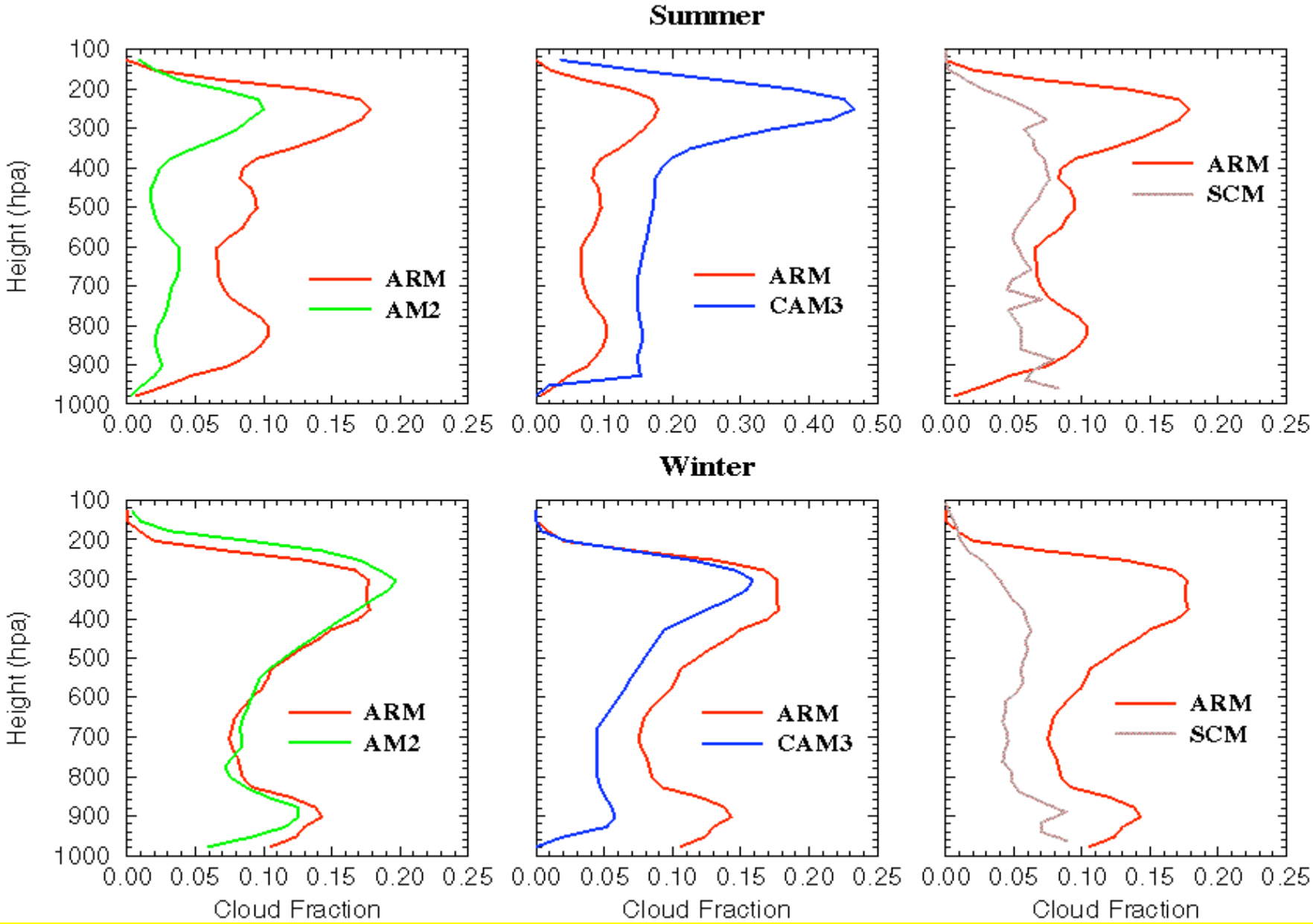
➔ One-hour temporal resolution,

➔~25 mb vertical distribution for each layer

➔35 levels from surface to 16 km.



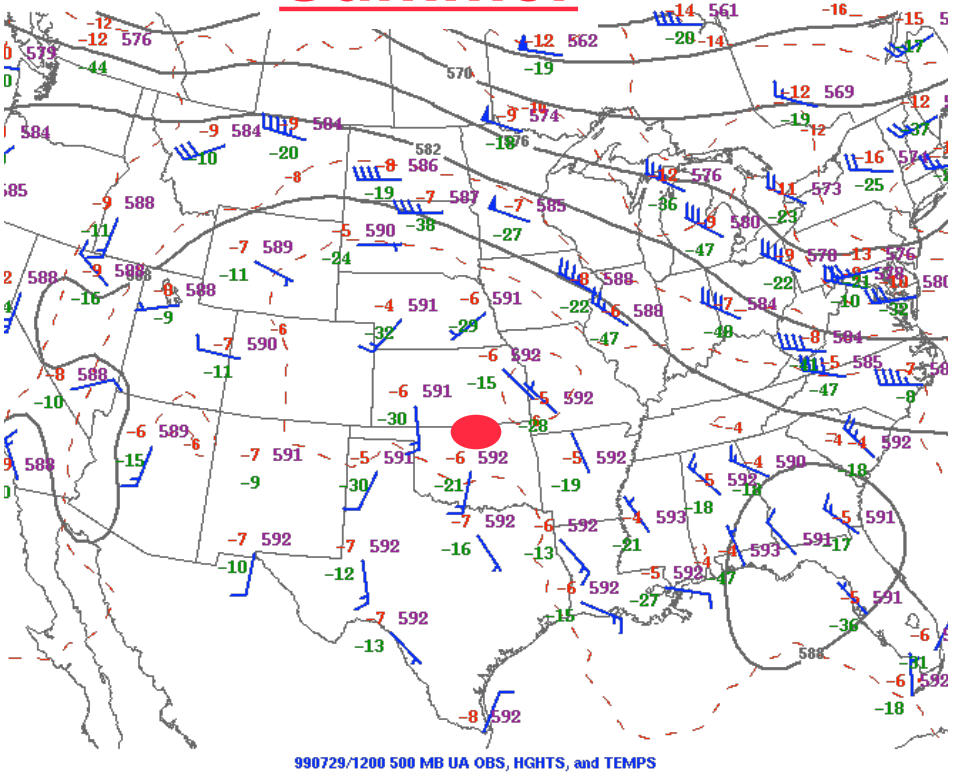
During transition seasons, AM2 and CAM3 agree well with radar observations, while SCM underestimates clouds above 900 mb.



During Summer, AM2 and SCM underestimate, but CAM3 overestimates clouds.
During Winter, AM2 agrees well, but CAM3 and SCM underestimate clouds

Synoptic Patterns impact on model simulations

Summer

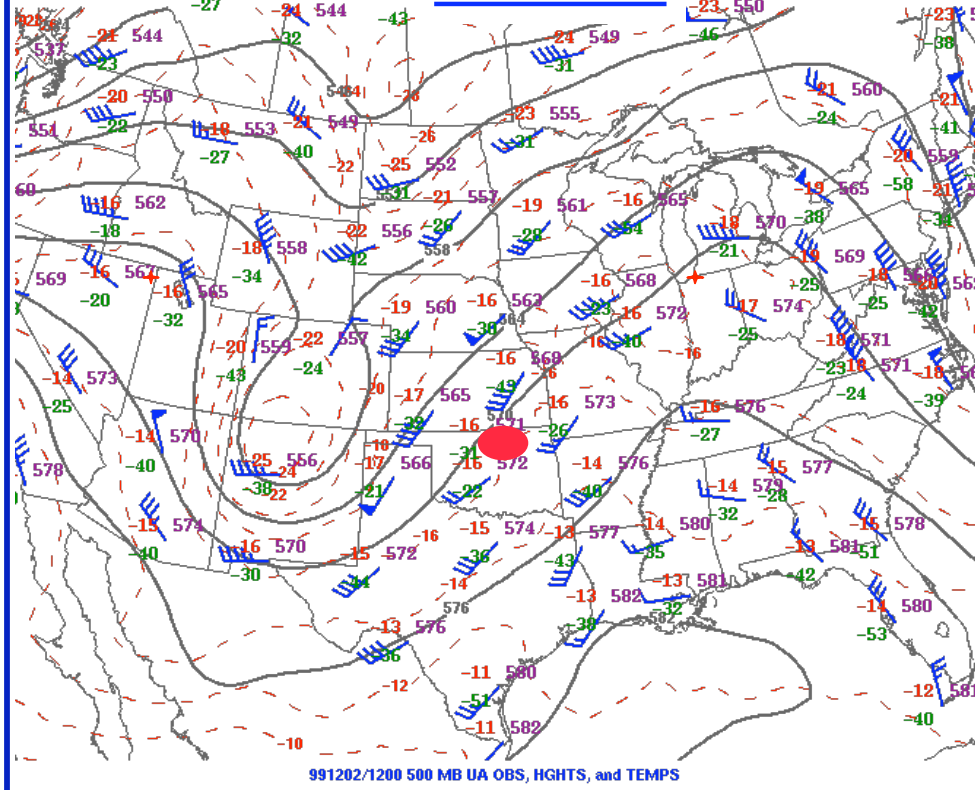


Models simulated less clouds

➔Upper-level ridging and high pressure

➔No large-scale forcing

Winter



Models simulated more clouds

➔SW/LW troughs

➔SW ridges ahead of deepening west cost troughs

Conclusions

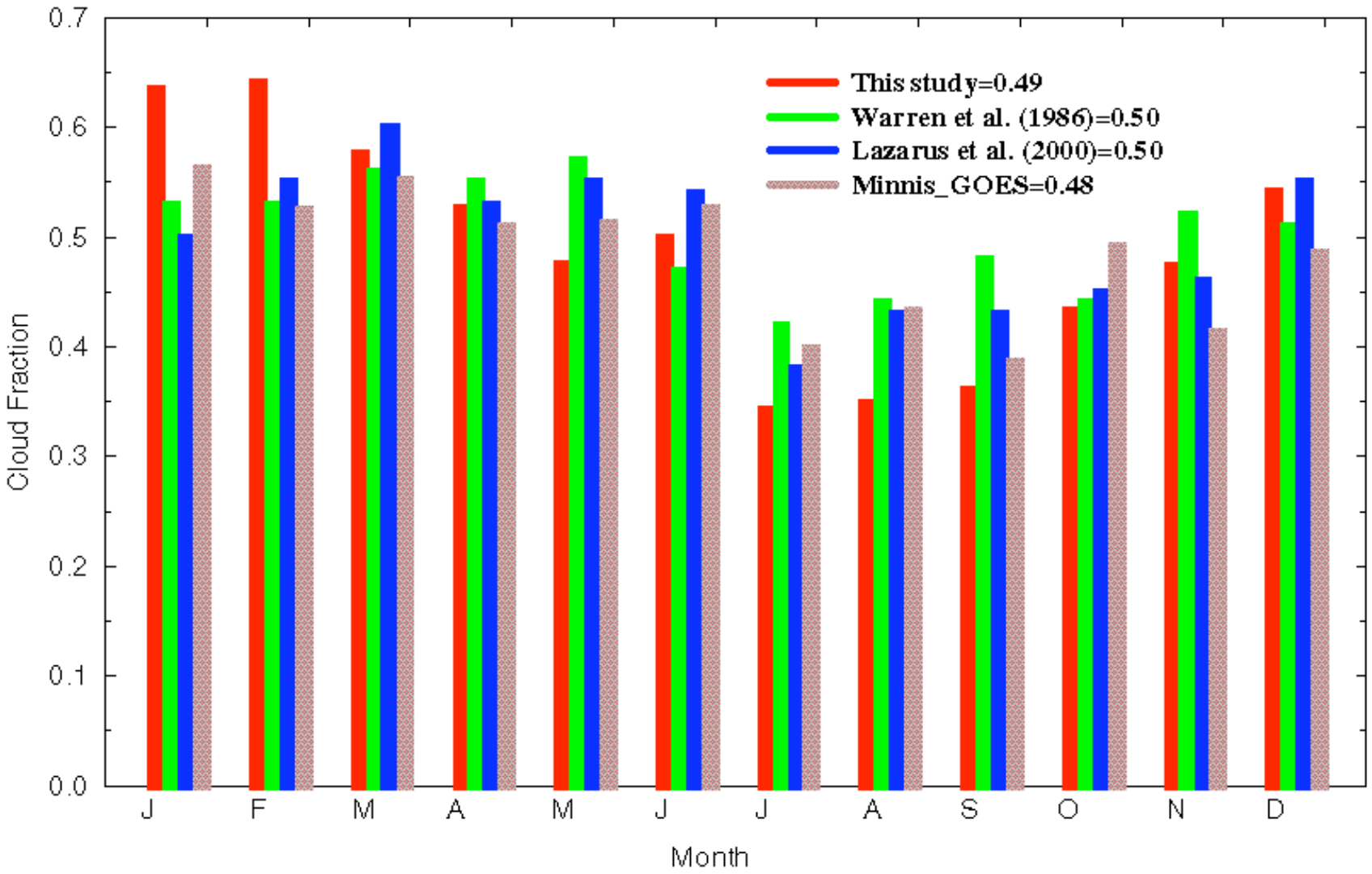
1. Compared to ARM derived cloud fraction, GOES has an excellent agreement except for Jan-Feb., AM2 agrees well, CAM3 overestimates during summer, while SCM underestimates throughout the year.

2. The Annual averaged NET radiation budget at
Surface: ARM =95.3, AM2=98.3, CAM3=95.4, SCM=101
TOA :GOES=-6.6, AM2=-2.6, CAM3=+7.2, SCM=-11
But both AM2 and CAM3 have 2-hr delay in diurnal cycle.

3. Compared with ARM derived vertical distributions of clouds, AM2 agrees very well except for Summer, CAM3 agrees well in transition seasons, while SCM underestimates clouds above 900 mb for 4 seasons.

Thanks for your attention!

A North Dakota Tornado Chasing Team, led by Aaron Kennedy.


Comparison of total cloud fraction at the ARM SGP Site
This study=0.49
Warren et al. (1986)=0.50
Lazarus et al. (2000)=0.50
Minnis_GOES=0.48
Cloud Fraction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
J
F
M
A
M
J
J
A
S
O
N
D
Month

How to match ARM, GOES, and Model results

- ARM (point) vs. GOES/Model (2.5°)

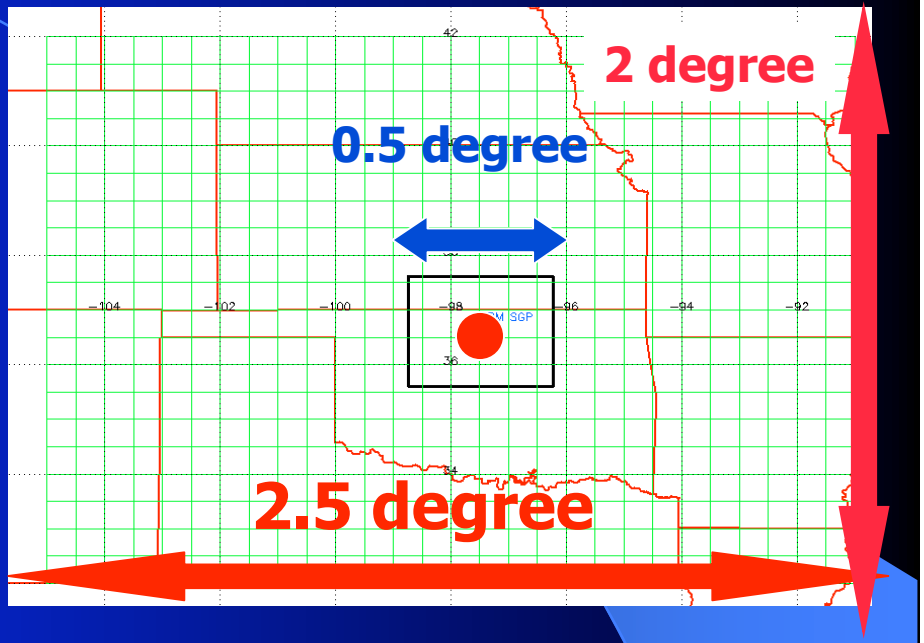
Temporal and spatial matching

ARM 1.5-hr occurrence = 0.62

GOES 0.5° occurrence = 0.62

ARM 5-hr occurrence = 0.75

GOES 2.5° occurrence = 0.75



- GOES vs. MODEL

Match in both temporal and spatial domains

Synoptic Pattern - Qualitative

- A total of 475 upper-tropospheric cloud (3+hr) cases
  - 68 Hits (14%),
  - 129 Partial Hits (27%)
  - 278 Misses (59%).
- More hits during winter
  - SW/LW troughs
  - SW ridges ahead of deepening west cost troughs
- Poorest performance during summer
  - Upper-level ridging and high pressure
  - No large-scale forcing

Miss (29 August 1999) **Hit (2 December 1999)**